Earth Independent Medical Operations [EIMO]
TRAINING Technical Interchange Meeting 26th October 2023
Background and Summary of discussion

Jay Lemery[1], Ben Easter[1], Kris Lehnhardt[1], Kurt Berens[1,2]

[1]Exploration Medical Capability Element, NASA-Johnson Space Center, Houston, TX
[2]KBR, Inc., 2400 NASA Parkway, Houston, TX

Background

A brief overview of EIMO and the framing of the current Crew Medical Officer (CMO) Training was presented to participants.

EIMO has been defined as *the gradual transition of medical care and decision making from terrestrial to space-based assets, enabling support of astronaut health and performance and reducing overall mission risk*. While a hallmark of this paradigm shift from low-earth orbit is that on-board care will increasingly become the responsibility of the astronauts for primary management and decision making, terrestrial assets will continue to be paramount in pre-mission screening and planning, as well as prevention, health maintenance and long-term care contingencies. New capabilities and systems that enable progressively more robust and resilient systems and crews will be necessary to reduce risk and increase probability of deep space exploration mission success.

The constituent elements of EIMO include: 1) pre-mission planning; 2) acute and prolonged medical decision making; 3) supplies and resource management; 4) task load balance; all interfacing within novel data management and decision-making frameworks.

Given the broad intersection with numerous human spaceflight stakeholders, EIMO will interface with multiple groups within NASA including, but not limited to:

A. The Exploration Medical Integrated Product Team (XMIPT)
B. Crew Health and Performance Integrated Architecture Team (CHP-IDA)
C. Space Communications and Navigation (SCaN)
D. Autonomous Medical Operations (AMO)

An aspiration for EIMO medical training is to identify the appropriate resources and learning opportunities to support continuity of KSAs for CMOs to provide clinical care for progressively autonomous medical operations.

EIMO TRAINING Technical Interchange Meeting

On 26th October 2023, ExMC convened a panel of Subject Matter Experts (SMEs) from NASA, broadly representing Headquarters, the Human Research Program, Medical Operations, the Human Health and Performance Directorate at JSC, the Health and Medical Technical Authority, the Flight Operations Directorate, and representation from

other Centers including: Ames Research Center (ARC), and Glenn Research Center (GRC). Representatives from the Canadian Space Agency also participated in this TIM. In addition, SMEs from industry included representation from the following entities: Axiom Space, Space Exploration Technologies Corporation, Level Ex, Shiny Box Interactive. Additional SMEs from academia included: University of Houston, Touro University, Weill Cornell Medical College and the Translational Research Institute for Space Health at Baylor College of Medicine. This group of stakeholders discussed the training issues related to facilitating EIMO.

Sub-topics for this discussion included the following:

- Pre-launch medical curriculum development
- Ground-based training on medical hardware
- Dental health
- Behavioral health
- Telemedicine
- Just-in-time training
- Simulation-based training (extended reality)

The meeting participants were provided with a baseline from which to begin the conversation. The group was informed that current curricula for CMO training ranges from approximately seven to thirteen hours based upon the crew member’s baseline knowledge, skills and abilities and is projected to increase significantly (eighty to one hundred-twenty hours) to support EIMO. The participants were made aware that there are currently one hundred-nineteen medical conditions used to model medical systems during an EIMO mission. Due to the expected task load, training opportunities will be limited and therefore must be highly prioritized, include live patient experiences and utilize extended reality tools. Methods for validation of training and assess skills retention will need to be developed to assure training methods are effective and enduring.

A series of questions were posed to the participants and the most salient opinions and points of the conversation are summarized below.

Current Crew Medical Officer (CMO) training consists of basic life support training and is approximately seven to thirteen hours in duration based upon the baseline medical knowledge, skills and abilities (KSA) of the trainee. It has been suggested that CMO for exploration class missions be increased significantly, up to 120 hours of pre-mission training – do you agree with this number? What types of training could be added to the current curriculum to enable Earth Independent Medical Operations?

The baseline KSA for a crew medical officer should approximate the KSA of a combat medical sergeant (18 Delta) although a physician-level KSA would be preferable. The range of pre-mission training (80-120hrs) may be sufficient but training must be tailored

to the KSA and should be contextual to assure performance under pressure. It is not the hours of training that are important but rather the attainment of validated competencies or milestones. Opportunities for self-review/assessment should be provided. While acute care is likely the bulk of expected duty for CMO, the prospect of long-term care and even palliative care must be considered since these are KSA that a medic will not have had prior training and/or experience. Consideration of training on resource usage should be given since the CMO will need to balance the use of resources for a single contingency if usage may compromise the ability to treat later conditions. Relevance to terrestrial medicine is exemplified in the emergency room *vs.* the intensive care unit dichotomy where the time and resources expended and training required vary significantly in support of acute- *vs.* long-term care.

Another key aspect to pre-mission training is the breadth and depth of the hardware and software on the vehicle/habitat to be trained on. Scope of mission, duration and available resources will all impact the pre-mission training regimen. A potential paradigm shift in the way training occurs was proposed by having the assigned CMO play a more active role in medical support preflight. Artemis has seen a shift away from Shuttle era operations toward a single, designated CMO due to split crew operations or other situations where relying on all the medical KSA in one individual poses unacceptable risk (*e.g.*, when the CMO becomes the patient). Recent operational changes implemented include an optional field medical training component (40hrs) to include hands-on clinical hours with the goal of solidifying confidence in conducting procedures such as iv insertion, urinary catheter placement and/or wound repair/closure.

Translational skills with universal application across a variety of conditions should be considered a priority for training with pre-exposure in a just-in-time training format so that when the procedure is needed it won't be the first time that the CMO has executed the steps necessary to complete the procedure. Sustainment training will be essential and utilizing the "see one, do one, teach one" methodology will reinforce learning and prevent the loss of perishable skills. Repetition is valuable and knowing how to do several procedures very well as opposed to having a broader KSA without core competencies is preferred.

Due to the expected task load during an exploration mission, in-mission refresher training might need to become a requirement to assure that all crew complete training. Since just-in-time training may be more easily applied for conditions that are not urgent/emergent, training for approximately 10% of the one hundred nineteen medical conditions that are expected to fall into that category may need priority for training using alternate methods. Final thoughts were related to diagnostic vs procedural training, with the latter being more important from a CMO physician perspective. Procedural skills

degrade more rapidly than diagnostic capability and the spaceflight environment challenges can negatively affect procedural execution regardless of proficiency level.

How has the terrestrial medical training world evolved in the last ten years and how could NASA incorporate some of those advancements into exploration astronaut training? What role would augmented reality (AR), virtual reality (VR) and/or other types of extended reality (XR) tools play in the training of CMOs for exploration class missions? What other nascent technologies now might be helpful training tools in the next 5-10 years?

There is a great opportunity to leverage what mixed reality technologies can offer with regard to CMO training. A significant amount of material has been created that can be utilized as part of a digital archive for extended reality modalities. Much of the work to date utilizes controllers which are not used in medicine and so there remains a gap to be closed to make the experience relevant and realistic from a clinical perspective. It is important to contextualize the CMO's physiological and behavioral status during and post-training since skills developed under rote training in nominal (non-stressful) conditions may rapidly degrade in a mission critical contingency environment. It will be important to establish reference baselines to assess effects of intra- and post-procedural physiologic perturbations on crew health and performance. Virtual reality (VR) allows training to be mapped to simulate the space environment which will lead to more meaningful training episodes. Creating the VR training must be done with open and frequent communication between the SME's and the VR developers to maximize the value of the training product. Tracking cognitive/behavioral parameters, *e.g.*, eye movement, pupil dilation, heart rate, blood pressure, temperature, with haptic indices in a team training environment could be an ideally productive approach.

Experience from the tectonic shift in training methods necessitated by the COVID pandemic will be valuable as the lessons learned make their way into the literature. Creation of materials that can be viewed in-flight as refresher training or just-in-time training will be important, but the ability to create content for unanticipated contingencies that can be uploaded to the CMO may also need consideration. Another important feature of the XR training environment is the ability of the crew to review their performance and generate a self-assessment.

Near-term future capabilities include the utilization of AI-prompting in AR/VR training environments. In addition, development of new methods to improve/accelerate the learning process, *e.g.*, vagal stimulation devices may augment the learning process.

Due to demands on astronaut time, it is impossible to train for the entire scope of medical scenarios that could occur during a mission. Possible approaches include training responses to specific scenarios/medical conditions and/or training general medical skills that are applicable across a wide range of scenarios. What are your thoughts on these approaches to enable Earth Independent Medical Operations?

One approach is to develop a library of "just-in-time" training (JITT) tools. Given communication latency and bandwidth constraints, what should the approach be for embedded, flight-ready/on-board JITT for medical autonomy versus partial reliance on ground support capabilities? Consider upload/download data transfers and asynchronous ground support for non-time sensitive situations.

NASA has done some preliminary work in this area and an example is the Autonomous Medical Officer Support (AMOS). The AMOS Tool is a linear, web-based information system that can access a range of levels of content based on the user's KSA. Several tech demos were successfully conducted on ISS with crew lacking in medical training to facilitate the use of ultrasound equipment.

The COVID disruption in medical education necessitated the generation of expansive libraries of video procedures which were used to train medical students, residents and fellows how to be doctors in the absence of actual patients. Companies like SonoSim developed a large number of simulations of ultrasound procedures. These simulations can be assisted (with guidance via RFID technology) or unassisted and could be leveraged for CMO training. Another example of enabling technology in the ultrasound space is the ButterflyIQ multi-use ultrasound probe which can be plugged into a phone or iPad. Image recognition technology also improved substantially and can be used to select the most clear and informative images to be sent to SMEs on the ground to reduce load on the limited communications bandwidth.

While training levels can be created that will facilitate targeted, highly efficient information transfer based on KSA, situational awareness training is critical for circumstances that exceed the capacity to treat (constrained by either resources or KSAs). It is assumed that a large body of digital reference material could be available to the crew, however, guardrails must be established to delineate when and if the responsibility and authority inherent in crew autonomous medical operations is possible and/or necessary. The culture of "failure is not an option" may not be applicable to CMO training for autonomous medical operations. To date mission durations have been short and communications have evolved to provide nearly 100% scripted on-orbit activities with virtually uninterrupted real-time support. Training must result in crews being comfortable with communication latency and occasional blackouts that could result in their needing to act with complete autonomy. Training to support crew autonomy must include parallel training for ground support

teams, flight surgeons and BME flight controllers. Planned and/or opportunistic autonomous experiences will facilitate future performance and generalized acceptance in the event of forced autonomy due to communication latency or total communication loss.

Pre-mission training is critical to mission success for low earth orbit (LEO) missions. As missions increase in distance from earth as well as in duration, refresher training of pre-flight skills may take on increased importance for maintenance of skills. How could we undertake a risk-based analysis for clinical skills that would merit JITT vs those where more formal proficiency maintenance would be deemed necessary?
Regarding the latter, what methods [and evaluation cadence] might be considered to evaluate retention and proficiency?

The perishable nature of the KSA required for a CMO will necessitate a refresher training cadence similar to terrestrial continuing medical education (CME) requirements. The concept of personalized training portfolios should be considered due to the variability in breadth and depth of KSA across the Astronaut Corps and within and between individual mission crews. Integrated crew training with an embedded "train the trainer" approach would benefit the crewmember's time in addition to strengthening crew bonding and trust in each other. An option to consider would be a fully integrated crew emergency medical training sim while in orbit. One method to improve training is gamification to make the task less tedious and capitalize on the competitive nature of the majority of astronauts. Many gaming-based tools have been created for use in training medical students, residents and fellows although success using this approach does not appear to be universal.

Proficiency assessment is challenging and historically has not been a formalized process within certain areas of crew training. Mastery level training is employed in areas such as EVA and robotics and priority for training time is given to defined mission tasks over contingencies. Historically, medical event contingencies have been rare due to the artifacts of short mission durations and exceptional quality of health in the astronaut population. Exploration missions will most certainly see an increase in medical contingencies that require intervention and the need to execute procedures will almost certainly rise concomitant with mission duration. Unlike medical operations to date, exploration missions will require for the first time primary medical care and routine medical checks and perhaps routine screening will become necessities to maintain optimal crew health and performance. For example, staggered blood draws to support routine screening could provide a robust method for maintaining venipuncture proficiency.

Quantification of the risk of not providing appropriate medical training would be challenging but important if achievable. Examination of the likelihood, consequence and procedure overlap across the expected medical condition list could assist in prioritizing the resources necessary to support medical management but also prioritize the type and amount of training to buy down risk. A paper soon to be published outlines the baseline

risk present if all treatments are available to the crew and all crew have the necessary KSA to perform procedures necessary treat any of the 119 medical conditions. The paper describes the effect on parameters such as “loss of crew life” and “task time lost” if the medical kits are not fully resourced or the crew KSA are below what is necessary to adequately provide treatment. This probabilistic risk assessment will be useful in identification of the training needed and may assist in prioritizing training curricula. An alternate approach was tested in a NSBRI-funded study called “Clinical Outcome Metrics for Optimization and Robust Training”. The study determined that having a physician as CMO did not provide a large difference in treatment outcome compared to a non-physician CMO. This observation was not entirely unexpected since astronauts have been shown to become proficient in numerous procedures that fall outside of their core area of expertise. Replication and expansion of similar analyses using IMPACT (next generation probabilistic risk assessment tool based on the Integrated Medical Model used for the ISS) would also inform training priorities.

Baseline medical KSA’s will be a fundamental skillset for exploration class missions. What should core competencies and medical disciplines be for CMOs in Earth Independent Medical Operations? What novel hybrid training might be needed [e.g., an emergency physician trained in appendectomy]? Is there a role for assessing [or testing?] ‘MacGyver’ qualities in an assessment rubric?

The concept of a “MacGyvernaut” is compelling and to some extent the selection process may already include biases toward individuals with MacGyver-like problem solving skills. If a CMO can implement alternatives to therapy that may be less invasive and/or less likely to be associated with harmful side-effects, then this type of MacGyver effect would be beneficial assuming there is no detriment to therapeutic outcome. This is not unlike the approach that general practitioners have utilized for decades, particularly in remote & rural areas and those with resource constraints. Training in this quality would likely be challenging and selection based on a rubric might be a more successful approach. Perhaps more important is the amount of clinical experience as opposed to procedural skill and ability to improvise on the fly.

While limited storage is a concern, inclusion of on-board reference materials could be invaluable in augmenting a CMO’s clinical decision making as well as provide a database for crew medical training. In your opinion, what reference materials would you characterize as critical for EIMO, and how might you prioritize them given these data constraints?

Communication bandwidth and latency issues will necessitate inclusion of on-board reference materials to support EIMO. Recent projections for lunar latencies in the 5 to 14

second range exceed the expected 3 second latency and have highlighted the importance of this issue. Inclusion of reference imagery may assist a crewmember in performing ultrasonography in the absence of ground support or when time to action is faster than time to response from ground support.

Fortunately, significant resource material has already been created and is available for use. Clinical reference databases such as UpToDate have already been used in-flight. An on-board library of short-duration, just-in-time videos for anticipated procedures would be highly enabling for EIMO. Highly interactive, conversational multi-modal AI based tools that are symptom driven would also be EIMO-enabling. An operationally important consideration is that all the above modalities need to be filtered to provide concise support with an option to take a deeper dive should the user need background, context or simply a larger amount of information. A final important consideration includes the pre-conditions for data to infer trust in our actions.

Human physiology (and presumably pathophysiology as well) is altered in space so a baseline understanding will be critical for a CMO since terrestrial references may tell only part of the story. Since very few astronauts are physicians, tiered supporting material may be essential to enable EIMO. All reference material and any AI-based clinical decisions support system will need to be vetted to assure that resources are accurate and reliable. Adaptation of bibliographic instruction techniques, *e.g.*, providing access to the information and then facilitating navigation of the resources might prove to be an effective means of conducting simulations.

Conclusion

We are grateful to all the participants in providing their time and energy to these deliberations, and for providing further clarity to EIMO Training and the overall direction of this endeavor.

A summary of takeaways:

- In terms of proficiency metrics, there was consensus that EIMO CMO training metrics be based on validated competencies or milestones, rather than a prescribed number of hours trained.
- Broad, translatable skills were deemed of most value—those with universal application across a variety of conditions.
- Repetition is invaluable for skill proficiency. Procedural skills were deemed more important for EIMO training—both because of residual ground support for diagnostics in an EIMO setting, and because procedural skills degrade more rapidly than diagnostic skills.
- Virtual reality (VR) will be a critical component, particularly via training mapped to simulate the space environment. Creating content must be done with close collaboration between SME’s and the VR developers to maximize the value of the product.

- A key part of XR, for training reinforcement, is the ability of the crew to review their performance and generate a self-assessment—which has been demonstrated to be an effective tool for retention and acceptance of feedback.
- Full integration of ground support teams, flight surgeons and BME flight controllers into the EIMO mission is a precondition for success, and training will be an important part of a shared understanding of when and if the responsibility and authority inherent in crew autonomous medical operations is possible and/or necessary.
- Likelihood, consequence and procedure matrices across the expected medical condition list will prioritize the resources and the type and amount of training to buy down risk.
- The “MacGyvernaut” is a compelling description of the scope of work of an EIMO CMO. This is not unlike the approach that general practitioners have utilized for decades, particularly in remote & rural areas with resource constraints.

MEETING PARTICIPANTS:

- *Augustine, Philip M. (JSC-SF211)*
- *Aunon-Chancellor, Serena (JSC-CB111)*
- *Asadi, Amran (Space Exploration Technologies Incorporated)*
- *Basso, Kailee K. (JSC-SF211)[KBR Wyle Services, LLC]*
- *Berens, Kurt L. (JSC-SF211)[KBR Wyle Services, LLC]*
- *Bernatovich, Michael (JSC-SF211)*
- *Bradshaw, Terri (JSC-SD111)*
- *Clarke, Mark (University of Houston)*
- *Daniel, Todd (Shiny Box Interactive)*
- *Dempsey, Donna (JSC-SF311)*
- *Dev, Sheena (JSC-SK311)[KBR Wyle Services, LLC]*
- *Ebert, Douglas (JSC-SD)[KBR Wyle Services, LLC]*
- *Gantwerker, Eric (Level Ex)*
- *Garner, Clifton (Level Ex)*
- *Gilkey, Kelly (GRC-MSX0)*
- *Gore, Brian (ARC-TH)*
- *Greene, Michael (JSC-OR)[Canadian Space Agency*
- *Harrison, Michael (Axiom Space)*
- *Hilmers, David (JSC-SD311)[Baylor College of Medicine TRISH}*
- *Jones, Billy (JSC-CK2)[KBR Wyle Services, LLC]*
- *Krihak, Michael K. (ARC-SCF)[KBR Wyle Services, LLC]*
- *Kuyumjian, Raffi (JSC-OR)[Canadian Space Agency]*
- *Landon, Lauren (JSC-SK311)[KBR Wyle Services, LLC]*
- *Lehnhardt, Kris (JSC-SD311)[IPA]*
- *Lemery, Jay (JSC-SD311)[IPA]*
- *Marchica, Andrea (GRC-MSX0)*
- *Martin, Annie (Canadian Space Agency)*
- *Mulavara, Ajitkumar (JSC-SK)[KBR Wyle Services, LLC]*
- *Nevins, Natalie (Touro University)*
- *Piper, Steven (JSC-SD311)*
- *Richardson, Rachel (JSC-SD2)[KBR Wyle Services, LLC]*
- *Rosenberg, Marissa (JSC-AD000)[Space Exploration Technologies Corporation]*
- *Shah, Kaushal (Weill Cornell Medical College)*
- *Smith, Tiffany (HQ-KA000)*
- *Stratton, Emily (JSC-SF211)[KBR Wyle Services, LLC]*
- *Whitmire, Alexandra (JSC-SA211)*
- *Wu, Jimmy (JSC-SA211)[Baylor College of Medicine-HRP TRISH]*
- *Yang, Justin (JSC-SA)[KBR Wyle Services, LLC]*
- *Zerdoum, Aiden (Level Ex)*

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